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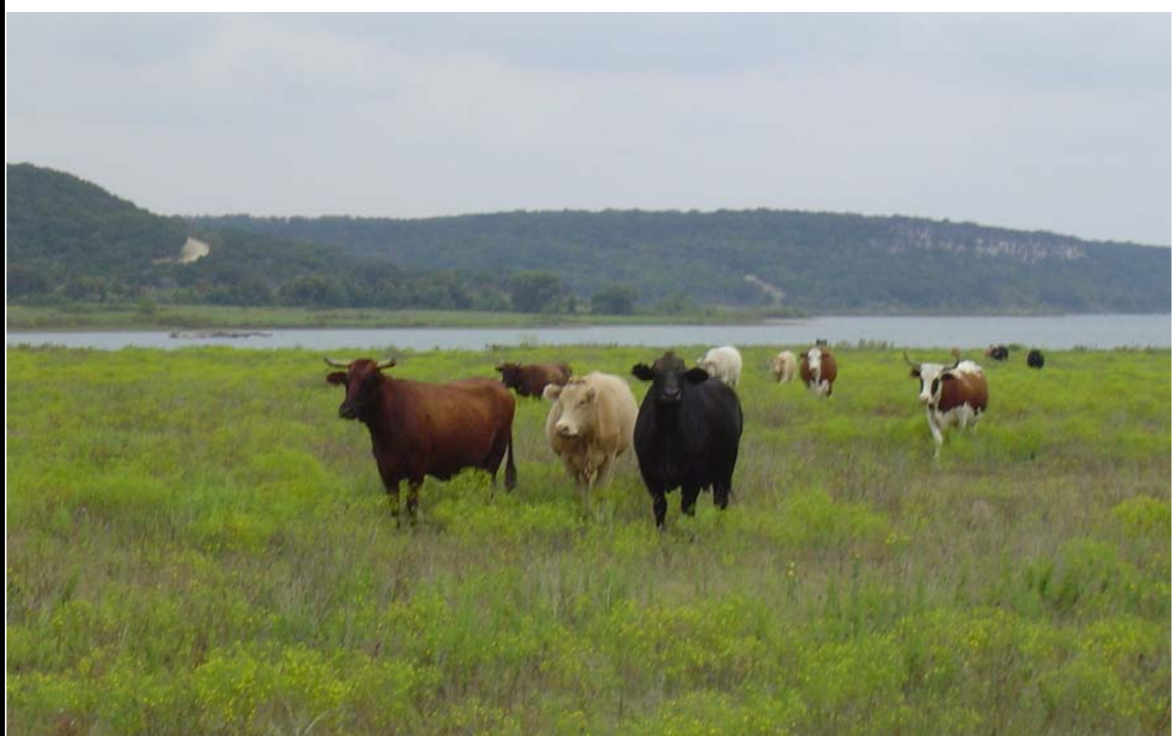
Cattle Grazing and Tracked Vehicle Training on Central and Southwest U.S. Army Lands

Potential Consequences for Grassland Ecosystems

John A. Guretzky, Jeffrey S. Fehmi, and Alan B. Anderson November 2005



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Cattle Grazing and Tracked Vehicle Training on Central and Southwest U.S. Army Lands:
Potential Consequences for Grassland Ecosystems

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ABSTRACT: Sustainability of training lands continues to be a primary concern for natural resource managers on Army installations. Tracked vehicle training, the main disturbance of grasslands, does not occur in isolation from other land uses including cattle grazing. Yet, no documented studies exist examining the interactive effects of these activities on soils and vegetation. The objective of this research was to begin filling this knowledge gap. This report reviews the literature documenting the impacts of tracked vehicle training and cattle grazing on soils and grassland plant communities and discusses potential interactive effects. Responses to tracked vehicle training generally included increased soil compaction, reduced cover and production of perennial grasses, disturbance of biological soil crusts, greater wind and water erosion, and less soil carbon storage. When overstocked, cattle grazing often results in similar effects. Concerns are greatest when heavy stocking results in loss of soil cover and replacement of perennial grassland species with annual grasses and forbs. Overall, the literature suggested that intensive cattle grazing of Army training lands might promote greater soil erosion and less desirable plant communities. The consequences of their interaction is likely to be greater in arid grasslands, where recovery mechanisms are slow and desertification is a concern.

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Conversion Factors

Non-SI* units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic inches	0.00001638706	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(5/9) x (°F – 32)	degrees Celsius
degrees Fahrenheit	(5/9) x (°F – 32) + 273.15.	kelvins
feet	0.3048	meters
gallons (U.S. liquid)	0.003785412	cubic meters
horsepower (550 ft-lb force per second)	745.6999	watts
inches	0.0254	meters
kips per square foot	47.88026	kilopascals
kips per square inch	6.894757	megapascals
miles (U.S. statute)	1.609347	kilometers
pounds (force)	4.448222	newtons
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square meters
square miles	2,589,998	square meters
tons (force)	8,896.443	newtons
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

***Système International d'Unités* ("International System of Measurement"), commonly known as the "metric system."

Preface

This study was conducted for Headquarters, Department of the Army, Office of the Director of Environmental Programs under A896, "Base Facilities Environmental Quality," Work Unit number 009F92, "Land-based Carrying Capacity." The technical monitor was William Woodson, DAIM-ED.

The work was performed by the Ecological Processes Branch (CN-N of the Installations Division (CN), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Dr. John A. Guretzky. The technical editor was Gloria J. Wienke, Information Technology Laboratory. Alan B. Anderson is Chief, CEERD-CN-N, and Michael Golish is Acting Chief, CEERD-CN. The associated Technical Director was Dr. William D. Severinghaus, CEERD-CV-T. The Acting Director of CERL is Dr. Ilker Adiguzel.

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1 Introduction

Background

As land in the United States continues to undergo development, the large, contiguous tracts of Army training lands have become important sites for the conservation of natural resources (Anderson 2002). In addition to supporting military training requirements, the Army protects federally listed threatened and endangered species (Goodman 1996). Military training activities, generally consisting of wheeled and tracked vehicle maneuvers, live-fire exercises, and field activities, can severely disturb ecosystems (Demarais et al. 1999), resulting in altered soil properties and plant and animal populations (Goran et al. 1983).

The impacts from tracked vehicles, the main disturbance of grasslands on Army installations, however, rarely occur in isolation from other land management activities or uses. Other activities and uses on U.S. Army lands include a wide-range of programs to support local, regional, and national values and may include grazing by livestock, prescribed burning, forestry, agricultural out leases, and wildlife habitat enhancement. Livestock grazing, through leases to local ranchers, is not uncommon on installations in the western United States and was likely common prior to land acquisition by the Army.

Cattle grazing on public range or grassland ecosystems in the western United States has been a controversial issue. Opinions vary from those that view public lands as a resource to be utilized with limited regulation or governmental oversight to those that contend that cattle grazing degrades ecosystems and should be restricted on public lands (Brown and McDonald 1995). Opponents have argued that livestock grazing in the West has displaced many native flora and fauna (Bock and Bock 1993), disrupted nutrient cycling and ecosystem functioning (Fleischner 1994), and severely disturbed riparian areas (Fleischner 1994; Trimble and Mendel 1995). Ranching also has been argued to be closely associated with the spread of exotic weed species, the alteration of food webs, and the extermination of poisonous snakes, burrowing animals, and large herbivorous and predatory mammals from western United States grasslands (Freilich et al. 2003). Though livestock grazing may not be suitable for highly-erodible lands (National Research Council 1994; Society for Range Management 2003), when properly managed, grazing has been regarded as a sustainable form of agriculture, compatible with other rangeland uses, and culturally and economically important to many communities (Society for Range Management 2003).

Because training land resources are finite, support multiple uses, and are important sites for conservation, information about the interaction of cattle grazing and tracked vehicle training on grassland ecosystems is vital to sustainable management of Army installations. Logistical constraints in conducting controlled experiments on Army lands, however, have precluded this interaction from being addressed.

Objective

The objective of this research was to examine the potential interaction of cattle grazing and tracked vehicle training on grassland ecosystems of Army installations in the central and southwestern United States. The research undertaken in this project supports the Army conservation user requirement titled "Land Capacity and Characterization." This user requirement identifies required research and development to improve the accuracy of the Army Testing and Training Area Carrying Capacity (ATTACC) methodology and Land Rehabilitation and Maintenance (LRAM) procedures. This research specifically supports Fiscal Year 2007 exit criteria "Develop an installation level method that identifies and incorporates into the model nonmilitary training land use and natural resources stressors (e.g., agriculture, grazing, fire, etc.)."

Approach

Researchers conducted a review of the scientific literature assessing the effects of tracked vehicle training on soil and vegetation of Army lands and the parallel literature examining the effects of cattle grazing on grassland ecosystems in the western United States. In this report, the review is followed by a discussion of the potential interaction of these activities on grassland ecosystems and Army installations.

Mode of Technology Transfer

The information from this study is being used to design field experiments that quantify the interaction of tracked vehicle training, cattle grazing, and other land uses. Information from these experiments will be incorporated into the ATTACC methodology and LRAM procedures as appropriate.

2 Literature Review

Literature examining the impacts of tracked vehicle training on soils and vegetation of U.S. Army installations represented studies primarily conducted in arid and semi-arid ecosystems of the central and southwestern United States (Table 1). Additional studies conducted elsewhere in the United States and internationally were reviewed if the methods and results were applicable. The methods used in the training impact studies ranged from designed experiments to observational studies. The designed experiments typically were arranged in randomized complete blocks with treatments consisting of tracked vehicle activity ranging from 1 to 74 passes. Control areas did not receive traffic from tracked vehicles. Vehicle pass treatments occurred under both wet and dry soil conditions in many of the studies, and an assortment of vehicles was used to apply tracked and wheeled vehicle disturbances. The vehicles included a suburban 4-wheel drive vehicle, M1A1 tank, M1A2 Abrams tank, M113 armored personnel carrier, M2 Bradley infantry fighting vehicle, and M-1 tank. The observational studies reviewed typically made comparisons of sites that had a history of damage from Army training compared to sites that appeared undisturbed. The disturbances generated by Army training in the observational studies were not specific to tracked or wheeled vehicles; disturbance from other military or land management activities may also have been important.

The review of the effects of cattle grazing on grassland ecosystems focused primarily on experimental studies conducted in arid, semiarid, and subhumid regions of the western United States (Table 1). The literature review covered effects of cattle grazing on grasslands like the Chihuahuan Desert in southeastern Arizona, southern New Mexico, and southwest Texas; the shortgrass steppe in eastern Colorado, mixed-grass prairies in central Oklahoma and Texas; and tallgrass prairie in eastern Kansas. These grassland types represented the native vegetation that occurred on Army installations such as Fort Bliss in southwest Texas, Fort Carson in Colorado, Fort Hood in central Texas, and Fort Riley in eastern Kansas (Goran et al. 1983). The review did not cover cattle grazing impacts on riparian areas because most tracked vehicle training on Army installations occurs on dry to moist sites that have minor slope gradients but are located away from water sources (Demarais et al. 1999).

Table 1. Number of reviewed studies documenting the effects of tracked vehicles and cattle grazing on grasslands.

Ecosystem trait	Response measured	Disturbance in grassland ecosystems					
		Tracked vehicle training			Cattle grazing		
		Arid	Semiarid	Subhumid	Arid	Semiarid	Subhumid
Soil quality	Compaction	5	1	2	4	8	0
	Water content	0	0	0	1	6	0
	Hydrology	0	2	2	3	16	0
	Erosion	4	2	1	4	12	0
	Biological crust cover	5	0	0	4	0	0
	Basal vegetative cover	0	0	0	0	0	0
	Aerial vegetative cover	4	6	1	1	8	0
	Litter cover	4	1	0	0	1	0
	Bare ground	5	4	1	0	4	1
	Carbon storage	2	0	0	5	14	2
	Nutrient cycles	1	0	0	2	9	3
Primary production	Aboveground	0	2	0	3	11	6
	Belowground	0	0	0	2	7	4
Plant community structure	Diversity	1	1	0	5	4	4
	Species composition	4	5	1	12	19	6
	Invasive species	1	0	0	1	1	1
	Woody plant establishment	0	0	0	0	1	0
	Spatial heterogeneity	1	1	0	3	2	0

To assess the potential interaction of tracked vehicle training and cattle grazing on grassland ecosystems, their individual effects on soil and vegetation were determined from literature reporting on a range of experiments conducted across the western United States. The literature often reported effects on soil compaction, soil cover, erosion, plant growth and productivity, species composition, and soil carbon storage (Table 1). Cattle grazing effects on plant productivity included above and belowground components. Several properties or processes of importance in grasslands ecosystems not specifically addressed in this report due to limited information about tracked vehicle training effects included the potential interaction of cattle grazing and tracked vehicles on nutrient cycling, maintenance of plant and animal diversity, and woody plant establishment.

3 Results

Military Tracked Vehicle Effects

Soil compaction

Researchers have found that tracked vehicle training increases soil compaction and may form ruts in the soil with lower depths than adjacent untracked areas (Table 2*). The packing together of soil particles results in increased bulk density and soil strength and decreased porosity, infiltration, and hydraulic conductivity of soil (Braunack 1986; Halvorson et al. 2001; Thurow et al. 1993). The spatial and temporal extent of disturbance imposed by tracked vehicle training depends on whether the soldiers drive the vehicles straight or make turns, the number of vehicle passes that occur, and the soil and vegetative conditions that exist at the training site (Ayers 1994). In general, greater soil compaction occurs as the number of tracked vehicle passes increase (Braunack and Williams 1993; Grantham et al. 2001), when tracked vehicles are driven on moist soils relative to dry soils (Halvorson et al. 2001; Thurow et al. 1993), and when vehicles are turned sharply as opposed to driven straight (Ayers 1994).

Ruts are formed in the soil when the contact pressure exerted by the vehicle exceeds the structural capacity of the soil (Ayers 1994). The soil surface adjacent to the tracks or ruts generally remains undisturbed when tracked vehicles are driven straight because little or no track slippage occurs and generation of shear forces is minimized (Ayers 1994). When conducting sharp turns, tracked vehicles generate shear forces that increase the width of soil ruts and track scars and disturb a greater percentage of ground (Ayers 1994). At the Yakima Training Center, Washington, passes by an M1A2 Abrams tank were shown to create ruts ranging in depth from 2- to 15-cm and increase bulk density of moist-tracked soils but did not affect bulk density or form ruts on a dry-tracked soil (Halvorson et al. 2001).

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* Table 2 is at the end of this chapter, on page 14.

Soil cover

Disturbance of soil and vegetation by tracked vehicle training reduces the amount of living and dead plant material and biological crusts that cover soil in grasslands (Table 2). Two years of moderate to heavy tracked vehicle training was shown to increase the percentage of bare soil by 17 percent on a military reservation in North Dakota (Prosser et al. 2000). Similar increases of bare ground followed tracked vehicle training in semiarid grasslands in Colorado (Milchunas et al. 1999; Shaw and Diersing 1990). In shrubsteppe of the Orchard Training Area, Idaho, turns of tracked vehicles generated 8 to 26 percent greater bare ground than straight-line tracks, reducing cover of both vegetation and biological soil crusts (Watts 1998). Biological crusts, important stabilizers of soil in arid grasslands, are readily disturbed and reduced in abundance by vehicle disturbances (Belnap and Gillette 1998; Belnap and Warren 2002).

Erosion

Researchers have concluded that tracked vehicle training increases the potential for erosion on Army lands (Table 2). Goran and others (1983) defined a disturbance continuum imposed by tracked vehicle training. A one-time pass usually has negligible effects on soils and vegetation except when vehicles are turned sharply or soils are moist when passed. Frequent and repeated traffic, however, results in increased soil compaction and slow recovery of vegetation (Table 2). Under intense, constant use, a largely denuded landscape develops, where maintenance is required to reduce erosion and off-site pollution (Goran et al. 1983).

When ground surfaces are bare, soil aggregates and structures are susceptible to destruction by raindrop impact (Thurow 1991). Vegetation protects soil and maintains soil by intercepting raindrops and absorbing their kinetic energy and improving soil properties through interactions between roots and soil (Castillo et al. 1997). Plants also funnel water down stems and provide pores at the base of the plant through which water can enter the soil rapidly. The presence of organic matter and root activity increases surface roughness of soil, thereby enhancing infiltration and decreasing surface water runoff (Greene et al. 1994; Wilcox et al. 1988). Estimates of sediment loss in runoff associated military tracked vehicle training at Fort Bliss training areas in New Mexico, ranged from 6 to 8 Mg ha^{-1} y^{-1} (Fuchs et al. 2003). On ranges in Texas, tracked vehicle training did not affect infiltration or interrill erosion rates of dry-tracked soil but increased interrill erosion on wet-tracked soils (Thurow et al. 1993).

Tracked vehicle training in arid and semiarid grasslands also increases the susceptibility of soil to wind erosion. At the Orchard Training Area, Idaho, one pass of a

M1A2 tank decreased the threshold wind speed, an indicator of soil surface stability and removed soil (Grantham et al. 2001). Four passes completely destroyed the vertical vegetation structure, crushing the vegetation into fine material that was easily removed with soil by wind (Grantham et al. 2001). When vehicles disturb biological soil crusts in arid ecosystems, common wind speeds frequently exceed the stability thresholds of the crusts, detaching and moving sediment (Belnap and Gillette 1998).

Plant growth and productivity

Presumably, tracked vehicle training reduces above and belowground net primary productivity of grasslands, though published reports of these data were not available (Table 2). The damage or removal of leaf area reduces the photosynthetic capacity of plants and therefore, plant growth (Briske 1991). Remobilization of carbon to support new leaf growth comes at the expense of roots, reducing their growth and increasing their mortality (Briske 1991). When defoliation or damage is too frequent, storage organs become deprived of carbon, the plant enters into a negative carbon balance, and it may suffer mortality (Sanderson et al. 1997). Soil compaction, deterioration of soil physical properties, and loss of soil resources through erosion also feeds back negatively on plant growth and productivity (Thurow 1991). Soil compaction restricts the storage of soil water and inhibits penetration and growth of roots (Braunack 1986), and increased runoff may result in the loss of essential plant nutrients and sediment, thereby lowering the productive potential of soil (Schlesinger et al. 2000).

Plant community

The literature shows that tracked vehicle training repeated over time results in retrogression of grassland plant communities. Goran and other (1983) suggested that occasional disturbance displaces species most sensitive to vehicle traffic and favors recruitment of disturbance-tolerant species. Tracked vehicle training repeated over time results in replacement of native perennial grasses and forbs with annual grasses and forbs, non-natives, and weed species (Demarais et al. 1999; Goran et al. 1983; Milchunas et al. 1999; Shaw and Diersing 1990). Under constant land use, soil compaction and erosion limits the recruitment of most seedlings, resulting in a barren landscape (Goran et al. 1983).

Imposition of tracked vehicle training at Pinon Canyon Maneuver Site in Colorado resulted in decreased basal cover of perennial warm-season grasses and increased cover of perennial cool-season grasses and annual warm-season forbs in shrub-grassland communities (Milchunas et al. 1999; Shaw and Diersing 1990). Non-native or exotic species, weeds, and annuals increased in abundance with imposition of tracked vehicle training at Fort Carson, Colorado (Milchunas et al. 2000).

Tracked vehicle training reduced cover of native perennial grasses and forbs in favor of increased cover of annuals and introduced species in tallgrass prairie at Fort Riley, Kansas (Quist et al. 2003). These changes were accompanied by decreases in plant species richness, diversity, and total vegetative cover (Quist et al. 2003). Reduced shading of shorter species by taller species and greater open soil by tracked vehicle training probably enables the recruitment of weeds and non-native or exotic species in prairie (Wilson 1988).

Soil carbon storage

Over the long-term, continued disturbance of soils and loss of productivity of plant communities by tracked vehicle training decreases carbon storage in soils on Army lands (Table 2). Training-induced soil compaction and restrictions to root growth limits inputs of organic matter to soils (Braunack 1986; Braunack and Williams 1993; Thurow et al. 1993). In desert environments, military training exercises reduce inputs of soil carbon and nitrogen from biological soil crusts through either direct disturbance (Belnap 2002) or through sandblasting of these organisms by sediment-laden wind (Belnap and Gillette 1998). Soil carbon and nitrogen have been identified as ecological indicators that can be used by military land managers to identify changes in soil from training activities and to rank activities on the basis of soil quality (Garten, Jr. et al. 2003). At Fort Benning, Georgia, sites undisturbed by military training had greater soil carbon and nitrogen in particulate organic matter than moderate use, heavy use, and remediated sites (Garten, Jr. et al. 2003).

Cattle Grazing Effects

Soil compaction

Cattle grazing generally compacts soil to some extent (Table 2), even under conditions managed to minimize soil degradation (Greenwood and McKenzie 2001). The pressure exerted on soil by a grazing animal is a function of the animal's mass, foot size, and kinetic energy and is comparable to that of mechanized equipment (Greenwood and McKenzie 2001). Most of the force applied is vertical, but pressures increase when an animal is moving as shear forces are generated, thereby increasing soil compaction (Greenwood and McKenzie 2001).

The amount of soil compaction generated by grazing animals is dependent on soil moisture. On dry soil, compaction is typically limited to the upper 50 to 150 mm and may be ameliorated through wet and dry cycles, growth and decay of pasture roots, and action of soil animals (Greenwood and McKenzie 2001). Treading on wet soil forms hoof prints often greater than 40 mm deep and puddles of water (Greenwood and McKenzie 2001). Compaction, however, typically is greatest at soil moisture levels between 20 and 30 percent of field moisture-holding capacity (Krueger et al. 2002). Wet soils give way or deform under pressure, with less compaction than soils with intermediate moisture content (Greenwood and McKenzie 2001). Cattle grazing commonly compacts soils when stocked at heavy rates (Dormaar and Willms 1998) and on heavy traffic areas such as trails and near water sources (Trimble and Mendel 1995).

Soil cover

Cattle grazing may reduce soil cover consisting of living vegetation and dead standing and surface litter in grasslands (Table 2). The effects are dependent on the stocking rate (Holechek et al. 1998). As the stocking rate increases, a greater percentage of available forage is utilized, resulting in a decline of the living and dead vegetative cover that remains to protect the soil. Forage utilization rates reported in the literature typically have ranged from about 25 to 50 percent at light to moderate stocking rates and 75 to 90 percent at heavy to very-heavy stocking rates (Milchunas and Lauenroth 1993). Forage utilization rates that do not maintain a threshold level of living and dead vegetative cover do not protect soil from erosive forces of wind and water (Thurow 1991; Weltz et al. 1998).

Erosion

The influence of cattle grazing on the physical properties of soil and the cover of living and dead plant material may feedback on soil stability in grasslands (Table 2). Diminished cover of living and dead plant material facilitates splash erosion, where raindrops dislodge soil particles and poor infiltration enables fine soil particles to be suspended in runoff water (Krueger et al. 2002). Concentration of runoff water into rills or flow paths along the soil surface transports sediment down slope (Krueger et al. 2002). Water flows generated from thunderstorms or rapid snowmelt events also may create gullies or deep incisions into hillsides where soil is rapidly eroded (Krueger et al. 2002). Rill and gully erosion generally only occur on steep and bare surfaces but have been associated with heavily used livestock trails (Trimble and Mendel 1995). Treading by cattle on steep slopes also may shear and dislodge soil down slope (Trimble and Mendel 1995). Near ponds or streams, this frequently causes banks to loosen and erode, contaminating water with sediment, bacteria, and nutrients (Krueger et al. 2002).

In arid and semiarid grasslands, cattle grazing may increase the potential for wind erosion. Grazing-induced reductions of perennial grass cover and the concentration of soil resources under shrub species has enabled the desertification of arid grasslands in the southwestern United States (Schlesinger et al. 1990). Barren areas between the shrubs are particularly vulnerable to wind erosion (Okin et al. 2001). Treading from cattle also destroys biological crusts that function to stabilize soil and increase carbon and nitrogen resources in desert soils (Belnap and Gillette 1998).

Overall, the effects of cattle grazing on grasslands and soil erosion are dependent on stocking rate and grazing management. Estimates of soil erosion on well-managed pastures from Iowa, Illinois, and Wisconsin have been estimated to range from 0.3 to 0.6 Mg ha^{-1} y^{-1} (Shiflet and Darby 1985). Within overgrazed pastures, soil erosion rates may be as high as 4.0 to 7.3 Mg ha^{-1} y^{-1} (Shiflet and Darby 1985). The national average soil loss (Table 1) from pastureland to sheet and rill erosion was estimated at 2.0 Mg ha^{-1} y^{-1} (U. S. Department of Agriculture [USDA] 2000). Estimated soil loss to wind erosion is considerably less at 0.2 Mg ha^{-1} y^{-1} (USDA 2000). Mean soil erosion was estimated from rainfall simulation plots in Texas rangelands to be 0.6 to 0.7 Mg ha^{-1} y^{-1} under heavy stocking rates and 0.1 to 0.3 Mg ha^{-1} y^{-1} under moderate stocking rates (Thurow et al. 1988). Erosion typically is minimized in rangelands stocked at moderate rates because plant cover is sufficient to maintain infiltration and sediment production rates comparable to ungrazed rangeland (Thurow et al. 1986).

Plant growth and productivity

Removal by livestock or damage to leaf and stem material is negative to individual plants (Belsky 1986). However, controversy exists as to how plant communities respond, either decreasing in productivity, showing no response, or increasing in productivity through compensatory growth mechanisms (Dyer et al. 1993). Overall, the literature suggested that generally cattle grazing reduced aboveground net primary productivity (ANPP) of grassland plant communities (Table 2; Briske and Heitschmidt 1991; Milchunas and Lauenroth 1993). Belsky (1986) contended that examples of compensatory growth were rare, and cases that showed overcompensation occurred in monocultures on moisture- and nutrient-rich soils, conditions not typical of western rangelands.

Reports in the literature of the effects of cattle grazing on belowground net primary productivity (BNPP) of grassland plant communities have been mixed (Milchunas and Lauenroth 1993). Experiments in mixed-grass prairies showed that light to moderate stocking of cattle reduced the amount of standing dead biomass and surface litter but had no effect on ANPP or BNPP (Biondini and Manske 1996; Biondini et al. 1998). When more than 90 percent of the aboveground biomass was utilized under heavy stocking, however, both ANPP and BNPP were reduced (Biondini et al. 1998). Declines in belowground plant productivity may occur if grazing results in exposure of bare ground or transition toward plant communities dominated by annual grasses and forbs (Rice et al. 1998).

Plant community

Cattle grazing effects on plant community structure are likely dependent on climate and the evolutionary history of the grassland communities (Milchunas et al. 1988). In subhumid grasslands like tallgrass prairie, cattle grazing has generally been shown to increase native plant diversity by reducing cover of tall perennial warm-season grasses and increasing cover of short and mid-height warm- and cool-season grasses, annuals, and forbs (Collins 1987; Gillen et al. 1998; Hartnett et al. 1996). Gillen and others (1998) showed that the cover of short grasses increased as cover of tall grasses decreased with greater stocking rates in prairie of eastern Oklahoma.

In semiarid grasslands like shortgrass steppe, moderate to heavy stocking of cattle has produced only minor alterations to species composition and diversity (Hart 2001; Hart and Ashby 1998). Annual precipitation has been regarded as a more important factor than grazing affecting interannual variation in species composition and diversity (Biondini and Manske 1996; Biondini et al. 1998). As stocking rate increases in semi-arid grasslands, however, short grass species also increase at the expense of mid grass species (Taylor Jr. et al. 1997).

In arid grasslands, cattle grazing effects are dependent on multiple factors such as seasonal weather conditions, drought, burning, stocking rate, and land-use history (Drewa and Havstad 2001; Holechek et al. 2003; Milchunas and Lauenroth 1993; Valone and Kelt 1999). Light stocking of cattle, where use of forage species averaged 26 percent, sustained native perennial grasses and maintained good ecological conditions in the Chihuahuan Desert, New Mexico (Holechek et al. 2003). Moderate stocking, where use of primary forage species averaged 49 percent, was not sustainable as grazing coupled with drought decreased survival and frequency of perennial grasses (Holechek et al. 2003).

Most evidence suggests that reduced stocking rates, alone, are not sufficient to promote recovery of arid grasslands degraded from previous disturbances such as overgrazing. Overstocking of domestic livestock during the late 1880s contributed to extensive degradation of grasslands in the southwestern United States, promoting the establishment of many invasive forbs and woody shrubs that still persist today (Wildeman and Brock 2000). Livestock grazing is particularly detrimental to tall perennial bunchgrasses (Bock and Bock 1993), and time lags of 20 years or more following removal of livestock may be necessary for grass recovery in historic arid grasslands now dominated by shrubs (Valone et al. 2002). Valone and Kelt (1999) found results in shrub-invaded, arid grasslands contrary to those found in more humid grasslands—that grazing was necessary to maintaining plant species diversity. Milchunas and Lauenroth (1993) suggested that desert grasslands and shrublands historically have been grazed more intensively than their more humid counterparts, contributing to degradation of their plant communities and accelerated desertification.

In general, grasslands that evolved with grazing and frequent droughts may be less susceptible to negative changes of species composition and diversity with increasing grazing pressure (Milchunas et al. 1988). In semiarid grasslands like the shortgrass steppe, the dominant plant species adapt to drought and grazing by growing horizontally and rapidly following defoliation, leaving little area or resources available for invading plant species. Semiarid grasslands, which have a short history of grazing, however, consist of plant species with drought tolerance but that grow upright and slow following defoliation (Milchunas et al. 1988). Their open canopy enables rapid compositional changes and invasions by exotic species. Subhumid grasslands that have long histories of grazing, like the tallgrass prairie, are adapted to moderate grazing intensities because these communities consist of tall-, mid-, and short-grass species. Mid- and short-grass species occupy light- to heavily-grazed patches while tall species dominate ungrazed areas (Milchunas et al. 1988).

Soil carbon storage

Long-term experiments have revealed that cattle grazing effects on soil carbon storage generally are negligible (Table 2). Milchunas and Lauenroth (1993) reviewed experiments conducted on a global scale and across a range of environments and showed instances of both increased and decreased soil carbon in response to grazing. In Oklahoma, organic carbon concentrations in the surface 5 cm of soil have remained similar among grazed and ungrazed sandhill rangeland in a 50-year experiment (Berg et al. 1997). In fescue grasslands of Alberta, Canada, however, soil carbon has decreased after 44 years of heavy grazing pressure (Dormaar and Willms 1998). Over 50 years of heavy grazing by cattle, however, have not had a significant effect on most soil organic pools in shortgrass steppe (Burke et al. 1999). Cattle grazing may have little effect on soil carbon in grassland ecosystems because most soil organic matter inputs are from roots and removal of aboveground biomass during moderate grazing intensities represents a relatively small loss of carbon (Burke et al. 1999).

Table 2. Effects of tracked vehicle training and cattle grazing on grassland ecosystems.

Ecosystem property	Military tracked vehicle training	Cattle grazing	Combination of tracked vehicles and cattle grazing
Soil compaction	• Forms ruts and increases soil compaction on moist-tracked soil resulting in greater bulk density and strength and reduced infiltration, porosity, and hydraulic conductivity of soil • Magnitude of compaction increases are less on dry-tracked soil	• Compacts soil to some extent • Greater compaction occurs on moist soil and on frequently trampled areas such as trails and near water sources • Dry-treaded soils are likely to recover from hoof-induced compaction	• May not affect soils disturbed by tracked vehicles but addition of animal treading is likely to increase compaction and generate additional disturbance on portions of soils that were previously undisturbed by tracked vehicles
Soil cover	• Destroys living vegetation and biological soil crusts resulting in less soil cover • Litter generally remains following tracking • Greater soil exposure occurs over time as the frequency of training increases and plant productivity decreases	• Reduces living and dead plant material • Generally, soil cover is maintained when stocking rates are appropriate • Treading reduces biological soil crust cover in arid ecosystems	• Expected to result in greater reductions of living and dead plant material and biological soil crust cover
Erosion	• Increases the potential for wind and water erosion by disturbing soils and vegetation • Erosion likely on sites that receive constant use and where vegetative recovery efforts are impaired	• Increase splash erosion on compacted and exposed soils where infiltration and impedance of runoff is reduced • May increase wind erosion in semiarid and arid grasslands • Generation of rill and gully erosion generally is infrequent in grazing lands	• May further decrease infiltration rates and increase surface runoff, thereby increasing splash erosion and possibly generating rill and gully erosion on extensively-used sites • Likely to result in overall greater wind erosion in semiarid and arid ecosystems
Plant growth and productivity	• Destroys living plant material resulting in less photosynthetic capacity of plants and therefore, less plant growth • Increased soil compaction restricts root growth and alters plant-soil nutrient and water relations • Reduces above and belowground productivity of plant communities over time	• Results in immediate loss of photosynthetic capacity of plants and if defoliation is constant without adequate recovery periods, plant mortality may occur • Decreases aboveground plant productivity but effects on belowground productivity are negligible	• Likely to result in greater overall loss of photosynthetic capacity of plants, greater plant stress, and increased plant mortality, thereby resulting in less productive plant communities and impaired vegetative recovery efforts

Ecosystem property	Military tracked vehicle training	Cattle grazing	Combination of tracked vehicles and cattle grazing
Plant community	• Increases disturbance-tolerant, early-successional grasses and forbs at the expense of native, perennial grasses • Enhances invasion of non-native species, shrubs, and woody plants in semi-arid and arid grasslands	• Maintains perennial grasses and overall plant diversity when stocking rates are appropriate • Promotes invasion of non-native species, shrubs, and woody species when overstocking occurs	• Expected to further favor the retrogression of plant communities, increase disturbance-tolerant plant species, favor dominance by early-successional grasses and forbs, and promote invasion of non-natives
Soil carbon storage	• Has no immediate effects but constant and intense training that reduces root and litter inputs of organic matter to soil will reduce soil carbon storage	• Has negligible effects on soil carbon storage when forage utilization rates are moderate • Decreases soil carbon storage over time if constant reductions of litter and root inputs of organic matter to soil occur	• Likely has negligible effects on sites where training is limited • May contribute to decreased soil carbon storage if grazing reduces litter and root inputs of organic matter to soil beyond that of training alone and hampers recovery of degraded training sites

4 Discussion

The literature reviewed showed that tracked vehicle training increases soil compaction and alteration of soil physical properties such as bulk density, soil strength, infiltration, and hydraulic conductivity in grasslands. Feedbacks on plant growth from these soil properties and the direct of effects of tracking reduce cover of vegetation and biological soil crusts, resulting in increased potential for wind and water erosion, less productive plant communities, and less soil carbon storage. These effects are magnified as the number of vehicle passes and frequency of training increases and when training occurs on moist soils. Repeated over time, tracked vehicle training results in replacement of native perennial grasses with early-successional grasses and forbs that rapidly establish in disturbed grassland canopies. Under constant training, a largely-barren landscape results (Goran et al. 1983).

Cattle grazing also increases soil compaction, although, on dry soils it is ameliorated through wetting and drying cycles, growth and decay of roots, and action of soil organisms (Greenwood and McKenzie 2001). Lasting effects of animal treading generally are greater on moist soils and where hoof action becomes concentrated, such as near water sources or on frequently worn trails (Trimble and Mendel 1995). Overall, the effect of most concern from cattle grazing on grassland ecosystems is when cattle activities result in the loss of soil cover (Thurow 1991). Greater utilization of forage occurs as stocking rate increases, resulting in less surface litter accumulation and plant cover (Milchunas and Lauenroth 1993). Typically, a threshold level of cover is necessary to sustain rainfall infiltration of soil, impede runoff, and maintain stability of soils (Weltz et al. 1998). In arid and semiarid grasslands, generally, only light to moderate stocking rates are appropriate as heavy stocking results in loss of native perennial grasses and the conversion of grasslands to shrublands or woodlands (Holechek et al. 2003; Milchunas and Lauenroth 1993). These changes are frequently accompanied by reduced primary production, increased wind and water erosion, and invasion of nonnative species (Archer and Smeins 1991; Schlesinger et al. 1990). Appropriate stocking of cattle on more humid grasslands has been shown to increase native plant diversity by reducing dominance of tall perennial grasses and increasing the abundance of short- and mid-height grasses and forbs (Collins 1987; Gillen et al. 1998; Hartnett et al. 1996) with negligible effects on net primary productivity and soil carbon storage (Knapp et al. 1998; Rice et al. 1998).

Overall, these results suggest that the addition of cattle grazing to Army lands has the potential to create greater soil and vegetative disturbances, facilitating more soil erosion, less productive plant communities, and changes in species composition beyond that already induced by tracked vehicle training. Treading from cattle may increase compaction on portions of soils previously undisturbed by tracked vehicle training and work against natural recovery processes on disturbed portions (Table 2). Additional soil compaction resulting from grazing is expected to be greater on moist, bottomland soils than on dry, upland soils, and grazing of riparian areas may increase contaminant and sediment loads in surface waters on Army lands (Krueger et al. 2002). On Army installations located in arid regions, greater overall traffic from vehicles and livestock may result in greater disturbances to biological crusts (Table 2), generating greater soil instability and altering nutrient cycles (Belnap and Gillette 1998). Soils that are unstable from previous tracked vehicle training events may experience even greater erosion with addition of cattle grazing. Experiments conducted on rangelands in Texas showed that trampling of soils devoid of vegetation cover accelerated sediment losses 2- to 3-fold beyond that which occurred on barren soils that remained untrampled (Warren et al. 1986).

Regardless of whether cattle grazing and trampling results in greater soil disturbance or compaction, addition of cattle grazing on Army lands is expected to reduce the amount of living and dead plant material on soil surfaces (Table 2). Tracked vehicle training crushes and detaches existing vegetation, but removal of plant material is minimal from training sites as it remains to cover soils or is incorporated into the tracks (Milchunas et al. 1999). Grazing lands, on the other hand, are known to have less accumulation of litter on soil surfaces compared to ungrazed lands (Milchunas and Lauenroth 1993). The defoliation and removal of vegetation by herbivores reduces standing and dead plant litter. The force of raindrops on uncovered rangeland soils increases the likelihood of splash erosion, the detachment of soil particles, and through time, a progressive deterioration of soil physical properties (Thurow 1991). Less accumulation of surface litter and less basal cover from living plants also results in less infiltration and soil water storage as vegetative impedance of runoff is less (Thurow 1991). Therefore, greater reductions of vegetative cover through addition of cattle grazing may result in increased erosion from Army training sites and the loss of dissolved soil nutrients and nutrients attached to sediment (Table 2).

Cattle grazing also may further decrease the production and cover of native perennial grasses and favor the establishment of early-successional species on Army-training sites (Table 2). Canopy disturbance created by tracked vehicles is non-specific, damaging most plant species that occur within tracks (Demarais et al. 1999). Perennial grasses are at a disadvantage because vehicle disturbances favor early successional grasses and forbs (Milchunas et al. 1999, 2000) and fast-growing weeds and invasive species that establish in gaps opened in the tracks (Wilson 1988). Cattle grazing may place even greater pressure on these perennial grasses because they are often preferred as forage compared to early-successional grasses and forbs (Anderson and Briske 1995). Removal of their leaf area disproportionately compared to early-successional grasses and forbs may place the perennial grasses at an even greater competitive disadvantage (Briske 1991, 1996). Alternatively, native perennial grasses may be less tolerant to the combined disturbances of grazing and vehicle traffic. Frequent and intense damage or removal of leaf material generates stress on energy reserves, and grassland plants rebuild leaf area by remobilizing carbon from stubble, roots, stolons, and rhizomes (Sanderson et al. 1997). If defoliation or damage is too frequent, these organs may become deprived of carbon and regeneration of leaf material slows (Sanderson et al. 1997). Faster growth of the early-successional grasses and forbs following defoliation or damage would enable these species to gain a competitive advantage over native perennial grasses in grassland communities (Briske 1991, 1996).

Over the long-term, feedback mechanisms resulting from increased soil and vegetative disturbances, loss of sediment and nutrients to erosion, and species compositional changes through a combination of cattle grazing and tracked vehicle training may result in less net primary productivity and soil carbon storage on Army lands (Table 2). Loss of fertile topsoil and soil compaction reduces rooting depth of plants and soil organic matter accumulation. Disturbance of biological soil crusts results in less accumulation of carbon and nitrogen in desert soils. Declines of perennial grasses on Army lands may result in less belowground net primary production and organic matter inputs to soil.

Overall, the consequences of an interaction between cattle grazing and tracked vehicle training may be greater yet for Army installations located in arid lands throughout the Southwest than semiarid to subhumid lands of the Great Plains. Recovery from soil compaction and disturbance of biological soil crusts is particularly slow throughout the Southwest (Belnap and Warren 2002; Kade and Warren 2002; Webb 2002). In the Mojave Desert, tracks remained visible and soil crusts had not recovered 55 years after disturbance from tracked vehicles was generated during World War II-era training events (Belnap and Warren 2002). Full recovery from soil compaction was estimated to range from 70 to 680 years (Belnap and Warren 2002; Webb 2002). Eighty-five percent recovery was estimated at 92 to 124 years (Webb 2002). Low rainfall and lack of freeze-thaw events probably enforce the lack of resilience to disturbance found throughout desert environments (Webb 2002).

Livestock and other anthropogenic-related disturbances have been associated with the desertification of arid grasslands (Schlesinger et al. 1990). As these activities reduce the production and cover of perennial grasses, soil resources become more heterogeneous spatially and temporally, becoming concentrated below and depleted between invading shrubs (Schlesinger et al. 1990). Recovery periods for perennial grasses lost due to livestock grazing or other disturbances often exceed 20 years (Valone et al. 2002). Lack of full canopy and short- to mid-height growth forms of perennial grasses within arid grasslands with a relatively short history of grazing by livestock also may enable invasive species to establish and rapid changes in species composition upon disturbance (Milchunas et al. 1988). Furthermore, anthropogenic disturbances promote greater instability of degraded arid shrublands by enhancing aeolian removal and transport of dust, sand, and litter (Okin et al. 2001).

In more humid grasslands, cattle grazing may be a land use compatible with tracked vehicle training if current and projected training intensities are low, plant cover of soil is high, and indicators suggest that the soils are stable, watersheds are functioning effectively, and the integrity of the biotic community is intact (National Resource Council 1994). Livestock grazing is regarded as a sustainable form of agriculture and important culturally and economically to rural communities (Society for Range Management 2003), and environmental impacts often may be regulated by control of the timing and intensity of grazing and overall livestock distribution (Krueger et al. 2002).

5 Conclusions

Natural resource managers on Army installations need information about the impacts and interactions of land uses such as tracked vehicle training and cattle grazing on ecosystems. Overall, the literature suggested that cattle grazing in combination with tracked vehicle training may generate greater disturbance of Army lands, potentially reducing the area needed for training, or the ability of these lands to support training. Both activities increase soil compaction and reduce plant cover, and therefore, may result in greater soil erosion, less productive plant communities, and replacement of perennial grassland species with that of early-successional grasses and forbs. These potential interactive effects are likely to be of greater detriment on Army installations in arid regions where disturbances from vehicles and livestock enhance the potential for desertification and threaten the stability and long-term productivity of these ecosystems (Okin et al. 2001; Schlesinger et al. 1990). Cattle grazing has been regarded as a sustainable form of agriculture (Society for Range Management 2003) and may be compatible with tracked vehicle training on Army lands located in more humid regions if current and projected training intensities are low, plant cover of soil is high, and indicators suggest ecosystems are functioning properly (National Resource Council 1994). Further investigations will be necessary to assess installation-specific interactions and the appropriate balance between that of tracked vehicle training and cattle grazing or other land uses.

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14. ABSTRACT

Sustainability of training lands continues to be a primary concern for natural resource managers on Army installations. Tracked vehicle training, the main disturbance of grasslands, does not occur in isolation from other land uses including cattle grazing. Yet, no documented studies exist examining the interactive effects of these activities on soils and vegetation. The objective of this research was to begin filling this knowledge gap. This report reviews the literature documenting the impacts of tracked vehicle training and cattle grazing on soils and grassland plant communities and discusses potential interactive effects. Responses to tracked vehicle training generally included increased soil compaction, reduced cover and production of perennial grasses, disturbance of biological soil crusts, greater wind and water erosion, and less soil carbon storage. When overstocked, cattle grazing often results in similar effects. Concerns are greatest when heavy stocking results in loss of soil cover and replacement of perennial grassland species with annual grasses and forbs. Overall, the literature suggested that intensive cattle grazing of Army training lands might promote greater soil erosion and less desirable plant communities. The consequences of their interaction is likely to be greater in arid grasslands, where recovery mechanisms are slow and desertification is a concern.

15. SUBJECT TERMS

land management	grazing	tracked vehicles
ecosystems	military training	

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